fup

NASA TECHNICAL TRANSLATION | NASA TT F-15,307

USING THE ENERGY OF THE WIND FOR ELECTRIFICATION

V. R. Sektorov
Candidate in Technical Sciences, Moscow

Translation of: "Ispol'zovaniye Energii Vetra dlya Elektrifikatsii," Elektrichestvo, No. 3, March, 1953, pages 11-16.

(NASA-TT-F-15307) USING THE ENERGY OF THE WIND FOR ELECTRIFICATION (Linguistic Systems, Inc., Cambridge, Mass.) 18 p HC $4.00 CSCL 10A

N74-16801

Unclas
G3/03 30395

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 FEBRUARY 1974

STANDARD TITLE PAGE

1. Report No. NASA TT F- 15,307	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle USING THE ENERGY OF THE WIND FOR ELECTRIFICATION		5. Report Date February 1974
		6. Performing Organization Code
7. Author(s) V. R. Sektorov		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address LINGUISTIC SYSTEMS, INC. 116 AUSTIN STREET CAMBRIDGE, MASSACHUSETTS 02139		11. Contract or Grant No. NASW-2482
		13. Type of Report & Period Covered TRANSLATION
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WASHINGTON, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of: "Ispol'zovaniye Energii Vetra dlya Elektrifikatsii," Elektrichestvo, No. 3, March, 1953, pages 11-16.

16. Abstract

The article discusses the utilization of wind energy for generating electric power. Existing power generators utilizing wind energy are described and their use in agriculture is indicated.

17. Key Words (Selected by Author(s))	18. Distribution Statement UNCLASSIFIED - UNLIMITED

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	~~16~~ 18	3.00

USING THE ENERGY OF THE WIND FOR ELECTRIFICATION

V. R. Sektorov

The use of the energy of the wind in wind-driven electric /11 *
power stations is most feasible in joint operation with electric power stations of other types. The maximum quantitative effect as far as the generation of energy is concerned is provided by a wind driven electric power station (W.E.S.) having 100-1,000 kW units operating in regional and local power systems in which it is possible to utilize completely the output from many wind-driven installations, located to yield a large total power [2].

The largest wind driven generators (types D-18 and D-30) designed in recent years for industrial applications can be utilized effectively in agricultural power systems for joint operation with hydroelectric power stations, considerably increasing the output of such systems. Hydroelectric power stations, the foundation of the energy base of local systems, must have at least a three to five day regulation of flow in order to ensure economic operation together with wind-driven electric generators. In the event of limited possibilities for regulation of existing hydroelectric power stations, with a large reservoir surface, these capacities can be expanded by raising the edge of the basin.

In rural areas independent wind driven electric generators are used for work involving a small reserve, as well as in windy areas where there is a low population density, even without a reserve.

The possibilities of wind-driven electric generators with special battery devices are limited. Electrochemical batteries are used only for the smallest installations; they are economically unfeasible in other cases. The area of their application is very limited: powering radio-transmitting stations, illuminating

*Numbers in the margin indicate pagination in the foreign text.

railway stations or other particularly important consumers [6]. The use of direct current, associated with electrochemical batteries, is unsuitable for the majority of consumers, as it does not allow the energy to be transmitted over a distance.

Hydraulic storage by means of turboelectric pumping stations and other reservoirs is feasible with comparatively rarely encountered topographic and geological conditions and is suitable only when there is a considerable difference in level. In the far north, hydrogen storage may be suitable.

Soviet industry is now manufacturing two quiet-running wind motors, the TV-8 with 6 horsepower and the TV-5 with 2.5 horsepower (supplied in the form of a wind-driven pumping station) and two high speed wind motors, the D-12 and D-3.5 with a power of 14 and 1.5 horsepower respectively. The D-3.5 is manufactured to be sold together with an electric generator. Recently, the small wind powered electric generator unit D-2 with a power of 100 W and wind motors D-18 and 1-D-18 with a power of 30-50 kW have been added, and they are currently being turned out in experimental mass production. These types of motors have already been used to construct a number of experimental, agricultural wind powered electric generating devices (Figures 1 and 2).

Experience was gained with the equipment and parallel operation on a power line in the Crimea using a wind-driven electric generating assembly that had a wind wheel diameter of 30 m and a power of 100 kW [4,5]; this machine was destroyed in World War II in 1941. There are no technical obstacles to building modern versions based on this design. The maximum efficiency with which the energy of the wind is used by such an installation at the prsent time is 0.37-0.38, while its power under the conditions formerly used for the calculation would be 150-160 kW.

Hence, the experience and the equipment we have available make it possible to construct the following at the present time:

1) Wind driven electric power stations with 30-150 kW units and wind motors with a wind wheel diameter of 18-30 m for parallel operation primarily in local power systems;

2) Single-unit wind-driven installations with a power of 10-30 kW with 3-phase current and wind motors having wind wheels with a diameter of 12 and 18 m, for joint operation with some other type of power-generating facility of comparable power or for isolated operation of one wind-driven installation without reserve;

3) Small wind-driven electric generating units with a power of up to 1 kW, direct current, with a wind wheel diameter of 1-1/2 to 5 m, operating with starter batteries, for illumination, communications and the cultural needs of small areas, as well as for charging batteries;

4) Wind-powered agricultural installations with a power of 2-15 horsepower, working primarily with a mechanical drive, with some of the power being fed to an electric generator.

The high speed wind motors that are used in wind-driven electric generators, as a rule, require considerable wind speeds to start them turning; it is therefore desirable to have average annual wind velocities on the order of 5 m/sec or more at the installation site. The calculated wind velocities at which the wind-driven unit develops its rated power by means of the generator are usually selected to be 1.7-1.9 of the average annual wind velocity, which corresponds to the optimum economic utilization of the unit.

The parallel operation of a W.E.S. with some other power system poses the following technical problems: (1) The reliability of operation of the wind driven unit; (2) the

reliability of the operation of other electric power stations with redistribution of the load between them and the W.E.S. under conditions when the power of the W.E.S. undergoes rapid fluctuation; (3) limiting the load on the wind driven unit to some /12
permissible limit.

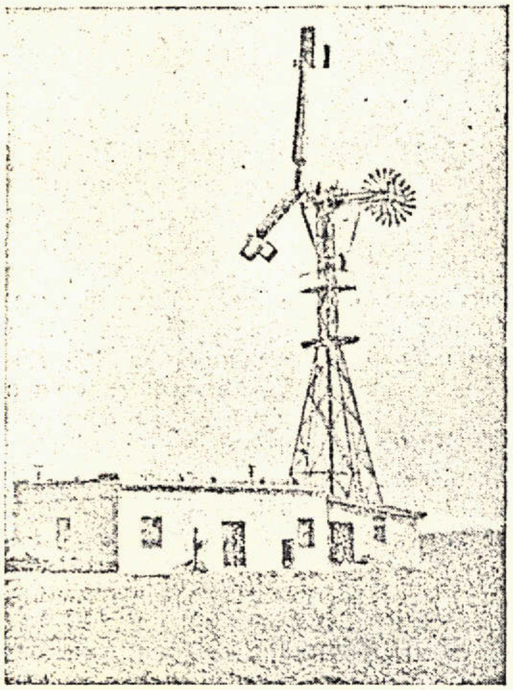

Fig. 1. Wind driven electric power station, D-18.

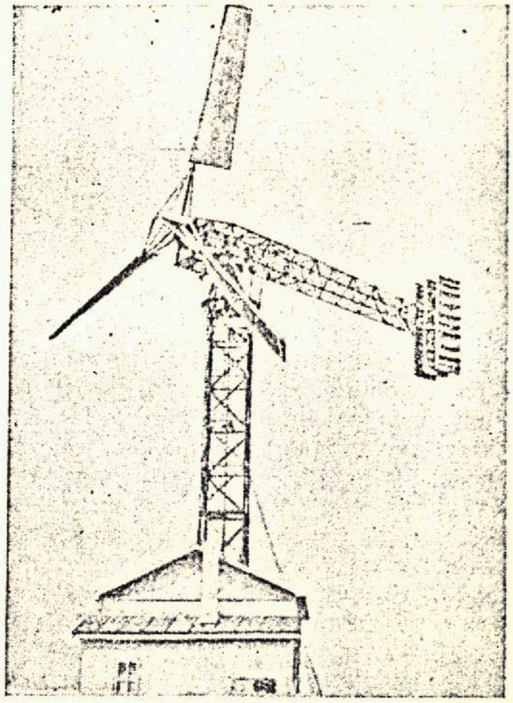

Fig. 2. Wind driven electric power station, 1-D-18.

Parallel operation of the D-18 and D-30 wind powered units with the system can be accomplished using two systems that have been tested in the U.S.S.R: with asynchronous or synchronous generators. A unit with an asynchronous generator is very simple as far as the design of the generator and switching system is concerned; it is reliable and has been tested by prolonged use at the experimental station of TsAGI [N. Ye. Zhukovskiy Central Institute of Aerodynamics] in the Crimea [4]. Reliable parallel operation of the wind powered unit with a powerful

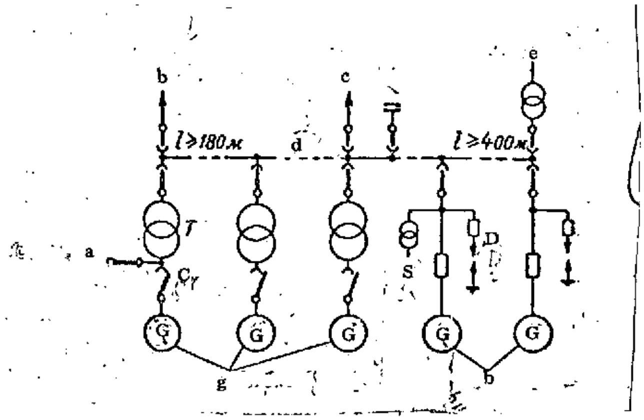

Fig. 3. Diagram of switching circuits in a wind powered electric station with D-18 (D-30 units) operating in the electric power system. (G--generator, T--step-up transformer, K--magnetic switch, discharger, S--switch, 6 kV). a--local load; b--output line; c--connection to the system; d--6 kV; e--local load; f--150 kW; g--50 kW.

electric power system was also achieved with a synchronous generator on the experimental installation of the D-18, All-Union Scientific Research Institute of Rural Electrification, as well as a powerful foreign wind powered installation using the D-53 [1, 3].

The reliability of a system of electric power stations working in parallel with a W.E.S., with rapid redistribution of the load between the stations, is a function of the constant inertia of the units of these stations and the pick-up time of the regulators of their motors.

In working with a powerful electric power system the redistribution of the load does not pose any difficulties since the power of the W.E.S. is small in comparison with the electric power system. The influence of the variations in the output of the W.E.S. decreases with an increase in the number of units of W.E.S. due to the difference in time between their output curves and the decrease in the ratio between the maximum and minimum on the graph.

Difficulties may arise when the power of the W.E.S. units and the other stations are the same. However, the decrease in the

variations of the W.E.S. and the balancing of the output curve of thewind-driven unit to the desired value, which is particularly important in isolated installations, as experiments have shown that were conducted by the laboratory of the All-Union Scientific Research Institute of Agricultural Mechanization, may be achieved by inertial storage by means of a heavy flywheel connected rigidly to the shaft of the generator and through a free-wheeling clutch to the wind motor. The inertial battery, increasing the constant inertia of the unit, makes it possible to change its power smoothly when the wind speed varies, creating a greater reliability for joint operation with another station and making it possible to fill in the most frequent brief interruptions in the power of the wind motor whose duration according to experimental data will not exceed t = 10-40 sec. /13
The stored energy in the flywheel when the speed or rotation changes from ω_1 to ω_2 will comprise

$$A = Pt = \frac{J_0(\omega_1{}^2-\omega_2{}^2)}{2},$$

where J_0 is the moment of inertia relative to the axis of rotation.

The free wheeling clutch enables the generator and flywheel to maintain its speed of rotation when the number of revolutions per minute of the wind motor drops.

The most pronounced brief interruptions in power will occur, as a rule, at low wind velocities on the order of 6-7 m/sec, when the power of the unit will be 25-50% of the rated value. Consequently the capacity of the battery can be determined on the basis of the condition that it must maintain at least 50% of the rated power of the unit. If we use an average period of interruption of 25 seconds and a permissible change in frequency of 10%, in order to smooth out the curve of the unit (D-18), the capacity of the battery would have to be about 6 kW per minute, which can be achieved by using a flywheel that has $J_o = 30$ kgm/sec^2 and a weight on the order of 1 to 1-1/2 tons.

The inertial battery with high capacity can be used at the present time on the 1-D-18 units of TSAGI, regulated by the rotation of the blades of the motor by the wind (safety-fail regulation). The use of an inertial battery with a wind motor of the stabilizer type has not yet been tested.

For work in an electric power system using both of these electrical systems it is necessary to limit the power of the windpowered unit at high wind velocities. In some designs of wind motors (for example the TSAGI 1-D-18 type) this is achieved by regulating the motor itself. In motors that have velocity regulation the power can be limited by linking the motor and the generator by sliding clutches of various designs or switching the motor to an operating mode with reduced aerodynamic characteristics. The latter method has been used at the Crimean installation of a D-30 [4]. Recently, several automatic devices have been proposed based on the use of this method. Limiting the power can also be achieved by using special shaped blades on a high speed windwheel which the studies of G. Kh. Sabinin indicate dissipate power at high wind velocities.

The design and operating scheme of a wind powered unit with an asynchronous generator was built and tested before the war for several years [2, 5]. Wind-driven electric power stations of this type must consist of units in the form of blocks: wind motor-generator-transformer, with generators having a voltage of 0.4 kV (for D-18 units), mounted at a distance on the order of 10 times the diameter of the windwheel apart in open areas and connected by air lines to one another and with the electric power system. With a higher power unit (type D-30), the generator voltage can be 3-6 kV with protection of the generators against atmospheric overvoltages by cable dissipators and discharges of the machine type. For compensation of the reactive power, used by the asynchronous generator, it is necessary to install static capacitors (Figure 3).

When working in this type of system, wind motors D-18 and D-30, which have velocity stabilizer regulation, can produce a limitation of the power by switching the motor (during periods of strong winds) to an operating regime with a reduced characteristic manually, later installing one of the proposed automatic systems.

The system for switching a single unit W.E.S. with a synchronous generator and with parallel operation in a system for a separate unit is similar to the one shown in Figure 3. Using an experimental D-18 unit for limiting the power of the unit, an electromagnetic asynchronous clutch was employed. To connect the W.E.S. to parallel operation, a method of automatic synchronization was employed which is currently used for hydro- and turbogenerators of all power levels. Sufficient experiments have been performed for equipment which currently uses single unit wind-driven generators for operation in parallel with electric power systems that are several times more powerful than the W.E.S.

At the present time, a study is being conducted of the operation of the D-18 wind driven generator with a synchronous generator in parallel with an electric power station of comparable power.

Prior to the manufacture of a sufficient number of D-18 and D-30 wind motors, parallel operation of the W.E.S. with rural hydroelectric power stations can be accomplished on the basis of the D-12 wind motor with stabilizer regulation. However, this version of the mechanical connection of many such wind motors into one aggregate by horizontal shafts is unsuitable, as well as being cumbersome and uneconomical. The weight of the connecting shafts and gears even when the relief of the terrain is favorable, would increase the weight of the equipment by 1-1/2 to 2 times. Moreover, the mechanical losses involved in transmission would increase severalfold due to the considerable increase in the number of bearings. The parallel operation of D-12 units with hydroelectric power stations of even low power can be carried out much more rationally by using asynchronous generators and electrical connections between the wind powered units.

For joint operation of the D-18, D-12 wind driven units with other installations of comparable power, a version of the system has been developed (VIN) with separate operation of the generators (Figure 4). In this version, several rural W.E.S. have already been built using the D-18 and 1-D-18 wind motors and the operating experiences being studied jointly with thermal power stations. The load is divided into three to four parts, feeding several outgoing lines, automatically switching in a certain order from the busses of the W.E.S. to the busses of the reserve facility and back again as a function of the available power of the wind-driven unit by means of magnetic switches. The impulse to switch when the power of the W.E.S. changes is given by the change in frequency of voltage on the busses, governed by the change in the rotational speed of the wind-driven unit. The influence of the variations in the load on the voltage is eliminated in all of these systems by means of compounding devices (transformers, stabilizers or type UKU-3 units).

The use of an inertial battery makes it possible to use wind-driven electric generators of the isolated type with type 1-D-18 wind motors and others without a reserve in the sparsely populated windy areas like the cattle-raising regions of the Kazakh SSR. The automatic mechanisms for switching the load

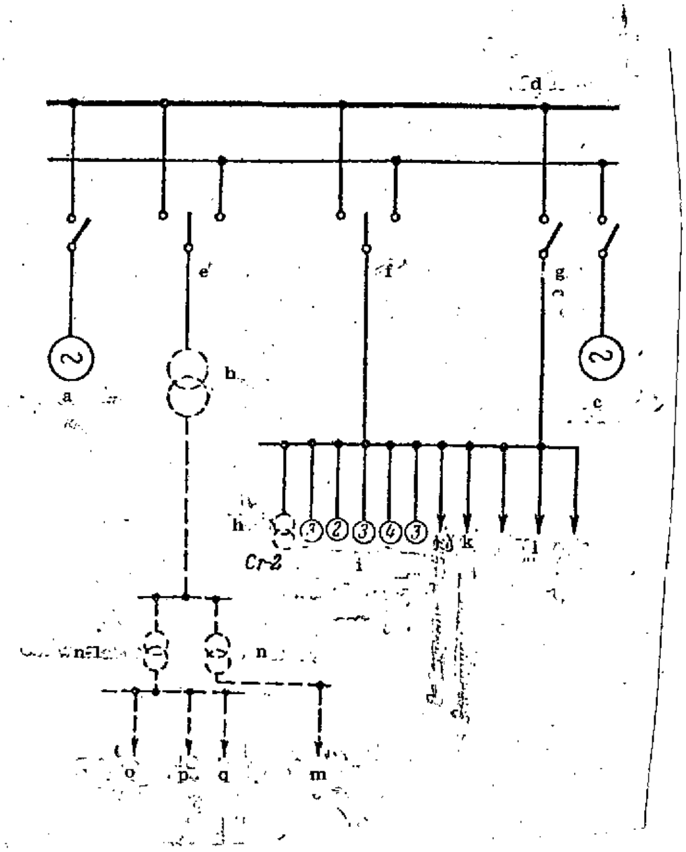

Fig. 4. Switching diagram of a W.E.S. (D-18) of the isolated type with a reserve thermal power source (Teleshevskaya Machine and Tractor Station). a--30 kVA, wind-driven electric power plant; b--10 kVA; c--35 kVA thermal electric power plant; d--400/230 volts; e--L1; f--L2; g--L3; h--10 kVA; i--electric motors of mechanical workshop; j--illumination, 3Kv; k--electric furnaces, 8 kW; l--electric furnaces, 10 kW; m--illumination 5 kW; n--5 kVA; n-1--Town of Nikol'skoye; o--illumination 5 kW; p--electric furnaces 8 kW; q--power load, 20 kW.

into parts is similar to that of the previous system. Such a wind-driven generator can ensure handling the power load on the basis of the demand chart for all windy hours, making it possible to electrify tedious agricultural processes such as pumping water, grinding feed, shearing sheep, and so forth. Constant electric illumination from the W.E.S. can be supplied using low voltage lamps (6 V) powered from the AC line through individual semiconductor rectifiers, using starter batteries when there is no wind and charging these batteries from the same rectifiers. One rectifier and two batteries (6 V, 80 AH each) will suffice for two to three collective farm houses.

In operating wind-driven electric power stations, especially those that work alone or with a slight reserve, the nocturnal output of the assembly when there is a shortage of the basic load must be put to use, organizing additional thermal loads in the form of heating furnaces and industrial and residential water heaters.

For water pumping and irrigating installations, it is usually most convenient to have electrical drive of centrifugal pumps from a wind-driven electric power generator. In this case, the electric pump operates in a normal fashion at a nearly constant rate of rotation.

The stable and efficient operation of a pump with mechanical drive is ensured by the proper choice of the transmission ratio of the mechanical transmission from the wind-driven generator on the basis of the inverse power characteristic $P = f(n)$. It is necessary to ensure an intersection of the pump curve with the characteristics of the wind motor near their peaks [10].

For operating a D-18 wind motor at full load with low thrust, three single stage centrifugal pumps can be used: $d = 150$, $Q = 25$ m/sec, $H = 12$ m, $n = 800$ rpm. The power consumed by each pump will be 8 kW under these conditions.

The small wind-driven electrical units of VIM D-3.5 and 100 D-2 TsAGI (Figure 5) can be used for small consumers and for charging batteries. The D-3.5 assemblies of earlier manufacture were used for illuminating individual buildings, powering communications equipment for agriculture, fishing fleets and in other applications. These units operate with acid or alkaline batteries in a buffer circuit. The D-3.5 unit uses a DC generator and an ordinary switching circuit for automobiles. In the new D-2 unit, a specially designed 3-phase current generator is used with excitation from permanent magnets that are mounted on the same shaft as the wind wheel. The poles of the magnets are made of laminations of illuminum-nickel steel. Having no sliding contacts or intermediate mechanical transmission between the wind wheel and the generator, the D-2 unit, regardless of the high speed of the wind wheel, will start operating at a very low wind velocity. The three-phase current is rectified by a Selenium rectifier which simultaneously protects the generator against the back current of the storage battery, doing away with the use of a relay.

To add an electrical section with small power to the wind-driven installations of the TV-8 class and others that work with mechanical drive to operating machines, the same electrical equipment is used as for small wind-driven electrical installations, and in particular the GT-4563 generator with a power of 1 kW or the GT-731 with 1.5 kW can be used; it is better to combine them with wind motors having V-belt drive. Multibladed wind motors commence operation at a wind velocity of 3.5 to 4 m/sec and the capacity of a storage battery for operation with such a wind motor may be 20-30% less than for high speed wind-driven units.

The technical data and the operating parameters of wind-driven electric generators of various types are shown in the table.

The field of wind utilization poses the following problems for scientific research departments in the near future: /15

1. Improvement of the design of existing high speed wind motors D-18 and 1-D-18 as well as the development of wind-driven

generator assemblies with these motors for isolated installations and in power systems.

The design of both wind motors is currently being improved. It has been considerably simplified. The weight of the wind wheel and of a number of other assemblies in the D-18 motor have been reduced. Changes have been made for purposes of satisfying all the conditions imposed on a wind-powered installation working in an electrical network. Parallel operation is being carried out with a system and a study is being made of the work of the unit with thermal power plants of comparable power.

2. Preparation for the construction of more powerful improved wind driven units with a wind wheel diameter on the order of 30-50 meters.

Studies are going forward to deal with the strength of the structural elements of wind motors based on the D-18 unit to compare the technical requirements for powerful units and the technical-economic bases for the operation of powerful wind-driven units in the power systems of regions being /16
irrigated in conjunction with the mighty building projects of Communism are being developed.

3. Improvement and construction of new designs of wind motors with medium and low power.

The construction of the TV-5, TV-8 and D-12 wind motors is planned for conversion to mass production, with a reduction of their weight.

A number of new, small wind-driven electric generators with a power of 0.1-1 kW is being developed.

Technical Characteristics of Wind Driven Electric Generators

Technical Data	Type of Unit					
	D-12	D-18 ZIM-GUSMP	1-D-18 TSAGI	D-20* TSAGI	D-3-5 VIM	100-D-2 TSAGI
Diameter of wind wheel, m	12	18	18	30	3.5	2
Number of blades	3	3	3	2	2	2
Power-speed coefficients	4.5	5	5	4.7	7	8.5
Speed of rotation of wind wheel, rpm	60	42	44	30	260-400	280-600
Method of regulation of the motor	Centrifugal with stabilizers	Centrifigual with stabilizers	Protective-sail	Centrifugal with stabilizers	Centrifugal	Centrifugal
Irregularity of motion, %	± 5	± 5	[illegible]	± 3	---	---
Calculated wind speed, m/sec	9.2	8.5	---	10.6	15	8
Installed capacity and type of generator	12 kW	G-35/6 or SGS 30/6 28 kW	G-35/6 28 kW	D-600/125 93 kW	GT-4563A 1 kW	Special Three-phase 30 W
Power on busses (kW) with Z = 8 m/sec	8	22	22	30	0.65	0.1
Gear ratio of mechanical drive	25	24	22.7/32	20.5	4	---
Weight of motor, kg	4500	16000	16000	49000	130	50 (with generator)
Wind speed at start of operation, m/sec	4.5	4.5	6	6.5	5	3.8
Type of current and voltage	3 phase 400 v or DC 120 v	3 phase, 400 v	3 phase 400 v	3 phase 230/6300 v	DC 24 v	3 phase 12 v
General efficiency of unit, %	25	27	26	—	20	15
Voltage regulator	Compounding device UKU-3	Compounding device UKU-3	Carbon-pile regulator RUN-111	—	RRD-4576A	---
Annual output (kWh) with $v_{av.ann.}$=5m/sec	25000	60000	60000	160000	1200	250
Annual number of hours of operation with $Z_{av.ann.}$=5m/sec	4800	4800	4800	3500	4000	5200
With full power	1000	1800	---	1000	300	2000
Use of rated power, hours	2100	2100	2100	1700	1200	2500

*. Prewar type, 1931-1941.

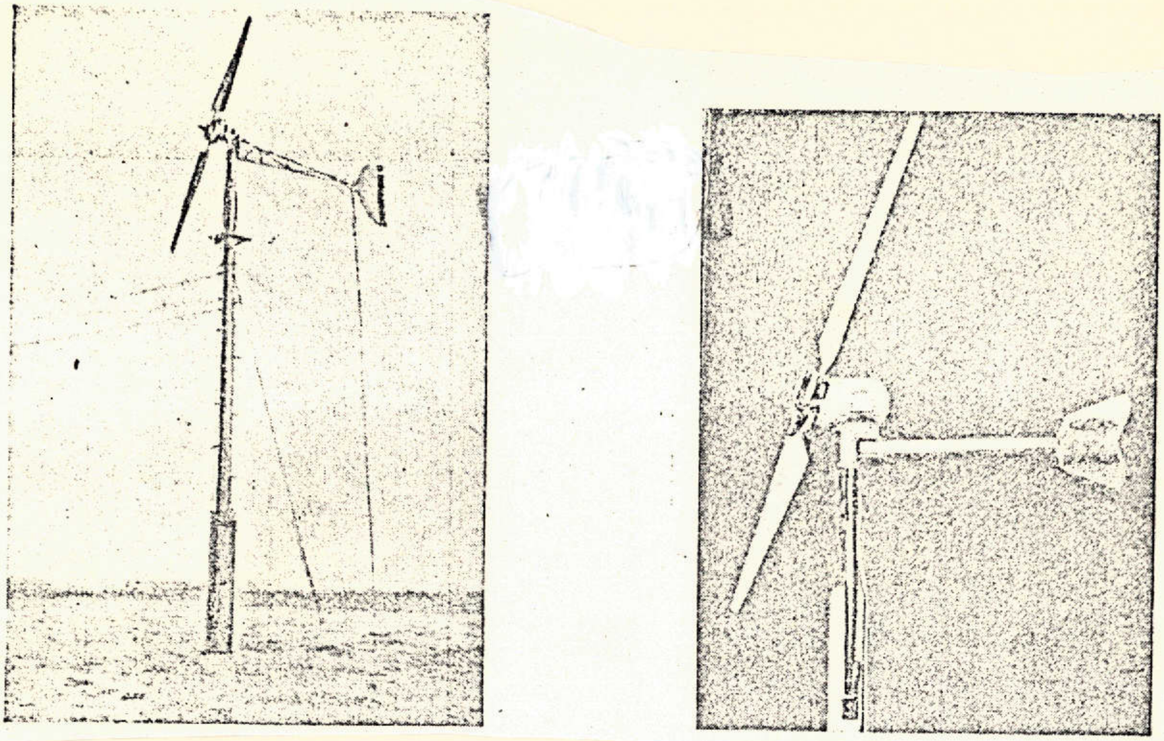

Fig. 5. Wind driven electric generators: VIM D-3.5-(left) and 100-D-2 TSAGI (right).

REFERENCES

1. V. N. Andrianov. "The Stability of a Synchronic Generator in Operation of a Wind Motor in a Power Grid." Elektrichestvo, No. 10, 1949.
2. V. R. Sektorov. "Operating Conditions and Types of Electric Wind Installations for Agricultural Regions." Elektrichestvo, No. 10, 1949.
3. V. R. Sektorov. "Wind Energy Abroad." Elektrichestvo, No. 10, 1951.
4. V. R. Sektorov. "The Balaklavskiy Experimental Electric Wind Station." Elektrichestvo, No. 19, 1933.
5. V. R. Sektorov. "The Contemporary State of Projection and the Experimental Construction of Electric Wind Installations." Elektrichestvo, No. 2, 1933.
6. V. I. Sidorov. "Vetrodvigateli v Arktike." (Wind Engines in the Arctic.) Izd. Glavsevmorputi, 1946.
7. V. I. Sidorov, V. S. Shamanin, A. S. Dobposerdov, and A. V. Karmishin. "Býstrokhodnyy Samoreguliruyushchiysya Vetrodvigatel'." (The High-Speed Self-Regulating Wind Engine.) D-18, Mashgiz, 1950.
8. I. T. Tazhiyev. "Energiya Vetra kak Energeticheskaya Baza Electrifikatsii' Sel'skogo Khozyaystva Kazakhstana." (Wind Energy as the Basis of Electrification of the Agricultural Economy of Kazakhstan.) Kazakhskoye OGIZ, 1949.
9. Ye. M. Fateyev. Vetrodvigateli i Vetroustanovki. (Wind Engines and Wind Installations.) Sel'khozgiz, 1948.
10. Ye. M. Fateyev. Vetroustanovki i ikh Primeneniye v Sel'skom Khozyaystve. (Wind Installations and Their Use in Agriculture.) Mashgiz, 1952.